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Einrichtung zur Strahlformung eines Laserstrahls

Die Erfindung betrifft eine Einrichtung zur Strahlformung eines Laserstrahls mit ringsektorförmigem Strahlquerschnitt, mit einem Spiegel, dessen Spiegeloberfläche als Ringsektor eines Rotationskörpers gestaltet ist. Eine derartige Einrichtung zur Strahlformung eines Laserstrahls ist beispielsweise durch die DE 44 21 600 C2 bekanntgeworden.

Bei der aus der DE 44 21 600 C2 bekannten Einrichtung zur Strahlformung wird aus einem ringsektorförmigen Laserstrahl mit radialer und/oder azimuthaler Polarisation ein rechteckförmiger Laserstrahl mit linearer Polarisation erzeugt. Dazu wird der Laserstrahl von einem Kegelsektorspiegel und einem parabolischen Zylinderspiegel geformt, wobei der Linienfokus des parabolischen Zylinderspiegels mit der Rotationsachse des Kegelsektorspiegels annähernd zusammenfällt. Allerdings sind bei dieser bekannten Einrichtung zur Strahlformung zwei Spiegel erforderlich. Der Kegelsektorspiegel formt den Laserstrahl in azimuthaler Richtung, zur Fokussierung oder Defokussierung des Laserstrahls in radialer Richtung ist ein zusätzlicher Spiegel erforderlich. Die auftretenden Brennweiten und Strahlabmessungen liegen in einer Größenordnung, dass bei sphärischen Spiegeln Abbildungsfehler durch sphärische Aberrationen auftreten. Um eine Auskopplung des Laserstrahls aus dem Laserresonator zu ermöglichen, ist es bei der bekannten Einrichtung zur Strahlformung mit einem Kegelsektorspiegel erforderlich, dass der Kegelöffnungswinkel geringfügig von 90° abweicht oder die Kegelachse nicht exakt mit dem Linienfokus des parabolischen Zylinderspiegels zusammenfällt. Dies hat zur Folge, dass der Strahlquerschnitt nur annähernd eine rechteckige Form und lineare Polarisation aufweist.

Es ist daher die Aufgabe der Erfindung, bei einer Einrichtung zur Strahlformung der eingangs genannten Art Abbildungsfehler zu verringern.

Diese Aufgabe wird erfindungsgemäß dadurch gelöst, dass die Spiegeloberfläche als Ringsektor eines parabolischen Rotationskörpers gestaltet ist. Die Spiegeloberfläche kann durch die konvexe oder durch die konkave Oberfläche des parabolischen Rotationskörpers gebildet sein. Bevorzugt ist der parabolische Rotationskörper als Rotationsparaboloid ausgebildet.

Ein parabolischer Rotationskörper entsteht durch Rotation der Parabel $z = x^2/a^2$, $a^2 > 0$ um eine beliebige, zur Symmetrieachse der Parabel parallele Rotationsachse. Die Krümmung der Parabel beträgt $d^2z/dx^2 = 2/a^2$ und ist für $a^2 > 0$ überall von Null verschieden. Ein Ringsektor eines parabolischen Rotationskörpers kann auch durch einen elliptischen Rotationskörper approximiert werden. Ein Rotationsparaboloid stellt einen speziellen parabolischen Rotationskörper dar, bei dem die Rotationsachse mit der Symmetrieachse der Parabel zusammenfällt.

Spiegeloberflächen, die als Ringsektoren von parabolischen Rotationskörpern gestaltet sind, formen den Laserstrahl sowohl in azimuthaler als auch in radialer Richtung. Abbildungsfehler durch sphärische Aberration treten bei derartigen Spiegeln grundsätzlich nicht auf, und bei exakter Parallelität zwischen Laserstrahlachse und optischer Achse sind sie auch frei von astigmatischen Abbildungsfehlern. Der Ringsektor eines parabolischen Rotationskörpers erzeugt einen Linienfokus auf seiner Rotationsachse,

während der Ringsektor eines Rotationsparaboloiden einen Punktfokus auf seiner Rotationsachse erzeugt.

Wenn der Ringsektor des parabolischen Rotationskörpers koaxial zur Ringsektorachse des einfallenden Laserstrahls angeordnet ist und wenn der ringsektorförmige Laserstrahl am parabolischen Rotationskörper um 90° reflektiert wird, wird die radiale und/oder azimutale Polarisierung in eine lineare Polarisierung überführt. Die effektive Brennweite des Ringsektors des parabolischen Rotationskörpers entspricht in azimutaler Richtung dem Krümmungsradius des ringsektorförmigen Laserstrahls. Durch Reflexion am parabolischen Rotationskörper bzw. am Rotationsparaboloiden wird der ringsektorförmige Laserstrahl in einen rechteckförmigen Laserstrahl geformt, wobei der parabolische Rotationskörperspiegel auf seiner Rotationsachse einen Linienfokus und der Rotationsparaboloidspiegel auf seiner Rotationsachse einen Punktfokus erzeugt. Da die optische Achse parallel zur Laserstrahlachse verläuft, treten keine astigmatischen Abbildungsfehler auf, so dass insgesamt das Auftreten von Abbildungsfehlern verringert ist.

Vorzugsweise ist im Linienfokus des Ringsektors des parabolischen Rotationskörpers bzw. im Punktfokus des Ringsektors des Rotationsparaboloids eine Blende (Raumfilter) vorgesehen, die aus dem rechteckförmigen Laserstrahl unerwünschte Beugungsanteile (Nebenmaxima) ausblendet. Dabei kann die relative Position zwischen Blende und Linien- bzw. Punktfokus des Ringsektors verstellbar

sein. Mittels einer Messeinrichtung kann die Temperatur der Blende erfasst und daraus ein Temperatursignal generiert werden, welches als Steuersignal zum Verstellen eines adaptiven Spiegels oder zum Verschieben der Blende dient.

Bei bevorzugten Ausführungsformen der Erfindung ist dem Ringsektor ein optisches Element mit einer oder mehreren Oberflächen nachgeordnet, die den Laserstrahl jeweils in zwei zueinander rechtwinkligen Richtungen formt bzw. formen. Mit diesem optischen Element können am Bearbeitungsort die gewünschten Strahlbreiten des Laserstrahls geformt werden.

In einer Weiterbildung dieser Ausführungsform ist das optische Element einteilig als Bifokuslinse ausgebildet, deren rückwärtiger Fokus vorzugsweise im Bereich der Rotationsachse des parabolischen Rotationskörpers liegt.

In einer anderen Weiterbildung ist das optische Element mehrteilig ausgebildet, beispielsweise durch eine Zylinderlinse und einen parabolische Zylinderspiegel oder durch eine Zylinderlinse und zwei parabolische Zylinderspiegel. Der rückwärtige Linienfokus der Zylinderlinse und/oder der rückwärtige Linienfokus des parabolischen Zylinderspiegels liegen bevorzugt im Bereich der Rotationsachse des parabolischen Rotationskörpers. Die Zylinderlinse kann den Laserresonator vakuumdicht abschließen und als

Auskoppelfenster dienen. Ein parabolischer Zylinderspiegel kann auch durch einen elliptischen Zylinderspiegel approximiert sein.

Der Ringsektor des parabolischen Rotationskörpers und die Zylinderlinse können zusammen ein Galilei-Teleskop für die ursprünglich radiale, nunmehr entkrümmte Richtung des ringsektorförmigen Laserstrahls, der Ringsektor des parabolischen Rotationskörpers und ein parabolischer Zylinderspiegel zusammen ein Kepler-Teleskop für die ursprünglich azimutale, nunmehr entkrümmte Richtung und die beiden parabolischen Zylinderspiegel zusammen ein Kepler-Teleskop für die ursprünglich azimutale Richtung bilden.

Die Erfindung betrifft auch einen Laser, umfassend einen koaxialen Laserresonator mit ringförmigem Entladungsraum und ringsektorförmiger Auskoppelöffnung sowie eine Einrichtung zur Strahlformung, wie sie oben beschrieben ist. Dabei ist der Ringsektor des parabolischen Rotationskörpers koaxial zur Ringsektorachse des einfallenden Laserstrahls ausgerichtet, d.h., die Rotationsachse des parabolischen Rotationskörpers fällt mit der Ringsektorachse des einfallenden Laserstrahls zusammen. Dadurch wird der ringsektorförmige Laserstrahl mit radialer und/oder azimutaler Polarisation in einen rechteckförmigen Laserstrahl mit linearer Polarisation geformt.

Weitere Vorteile der Erfindung ergeben sich aus der Beschreibung und der Zeichnung. Ebenso können die vorstehend genannten und die noch weiter aufgeführten Merkmale erfindungsgemäß jeweils einzeln für sich oder zu mehreren in beliebigen Kombinationen Verwendung finden. Die gezeigten und beschriebenen Ausführungsformen sind nicht als abschließende Aufzählung zu verstehen, sondern haben vielmehr beispielhaften Charakter für die Schilderung der Erfindung.

Es zeigt:

- Fig. 1 einen Laser mit einem coaxialen Laserresonator und einer erfindungsgemäßen Einrichtung zur Strahlformung des Laserstrahls;
- Fig. 2 einen Schnitt in nicht maßstäblicher Darstellung durch die in Fig. 1 gezeigte Einrichtung zur Strahlformung;
- Fig. 3 eine andere erfindungsgemäße Einrichtung zur Strahlformung des Laserstrahls in einer Darstellung analog der Fig. 1; und
- Fig. 4 einen Schnitt in nicht maßstäblicher Darstellung durch die in Fig. 3 gezeigte Einrichtung zur Strahlformung in einer Darstellung analog der Fig. 2.

Fig. 1 zeigt einen coaxialen Laserresonator 1 mit einem ringförmigen Entladungsraum 2, der von einer zylindrischen Außenelektrode 3 und einer darin befindlichen zylindrischen Innenelektrode 4 begrenzt ist. An dem in Fig. 1 rechten Ende des Laserresonators 1 ist der ringförmige Entladungsraum 2 durch einen ringförmigen Frontspiegel 5 mit einer ringsektorförmigen Auskoppelöffnung 6 und am linken Ende durch einen konischen Rückspiegel 7 begrenzt.

Der durch die ringsektorförmige Auskoppelöffnung 6 aus dem ringförmigen Entladungsraum 2 austretende ringsektorförmige Laserstrahl 8 ist radial und/oder azimuthal polarisiert. Außerdem enthält die Leistungsdichteverteilung unerwünschte Beugungsanteile (Nebenmaxima).

Der ringsektorförmige Laserstrahl 8 trifft innenseitig auf einen um 90° umlenkenden Ringsektor 9 eines Rotationsparaboloidspiegels, dessen Rotationsachse 10 coaxial zum ringförmigen Entladungsraum 2 und parallel zur Einfallsrichtung des Laserstrahls 8 liegt und dessen Brennweite in azimuthaler Richtung dem Krümmungsradius des ringsektorförmigen Querschnitts des Laserstrahls 8 entspricht. Durch Reflexion am Ringsektor 9 des Rotationsparaboloids wird der ringsektorförmige Laserstrahl 8 in einen rechteckförmigen Laserstrahl 11 geformt (d.h. entkrümmt) und auf der Rotationsachse 10 ein Punktfokus erzeugt. Im Bereich dieses Punktfokus ist eine Blende 12, insbesondere eine Düse, angeord-

net, die unerwünschte Beugungsanteile aus dem rechteckförmigen Laserstrahl 11 ausblendet.

Damit der rechteckförmige Laserstrahl 11 am Bearbeitungsort die gewünschten Strahlbreiten in beiden Richtungen besitzt, werden zur Strahlformung in der ursprünglich azimuthalen Richtung eine Zylinderlinse 13 und zur Strahlformung in der ursprünglich radialen Richtung ein parabolischer Zylinderspiegel 14, der auch durch einen elliptischen Zylinderspiegel approximiert werden kann, eingesetzt. Der rechteckförmige Laserstrahl 11 trifft auf die Zylinderlinse 13, die die ursprünglich radiale Richtung des rechteckförmigen Laserstrahls 11 nicht beeinflusst und einen parallelen Laserstrahl 15 in der ursprünglich azimuthalen Richtung erzeugt (Fig. 2). Der parabolische Zylinderspiegel 14 ist so im Strahlengang angeordnet, dass sich sein rückwärtiger Linienfokus etwa im Bereich der Rotationsachse 10 befindet. Durch geeignete Wahl der Brennweite des parabolischen Zylinderspiegels 14 wird ein radial paralleler Laserstrahl 16 mit der gewünschten radialen Strahlbreite erzeugt.

Der Ringsektor 9, die Blende 12, die Zylinderlinse 13 und der parabolische Zylinderspiegel 14 bilden zusammen die insgesamt mit 17 bezeichnete Einrichtung zur Strahlformung.

Fig. 3 und Fig. 4 zeigen eine andere Einrichtung 20 zur Strahlformung, bei der der ringsektorförmige Laserstrahl 8 außenseitig auf den Ringsektor 21 eines parabolischen Rotationskörpers trifft. Durch Reflexion an der konvexen Außenoberfläche des Ringsektors 21 wird der ringsektorförmige Laserstrahl 8 in einen rechteckförmigen Laserstrahl 22 geformt, wobei auf der Rotationsachse 23 des parabolischen Rotationskörpers ein Linienfokus erzeugt wird.

Damit der rechteckförmige Laserstrahl 22 am Bearbeitungsort die gewünschten Strahlbreiten in beiden Richtungen besitzt, werden zur Strahlformung in der ursprünglich radialen Richtung eine Zylinderlinse 24 und zur Strahlformung in der ursprünglich azimuthalen Richtung zwei parabolische Zylinderspiegel 25, 26 eingesetzt. Der Ringsektor 21 des parabolischen Rotationskörperspiegels bildet mit der Zylinderlinse 24 ein Galilei-Teleskop, das in der ursprünglich radialen Richtung einen parallelen Laserstrahl 27 erzeugt, und mit dem ersten parabolischen Zylinderspiegel 25 ein Kepler-Teleskop. Die beiden parabolischen Zylinderspiegel 25, 26 stellen zusammen ein weiteres Kepler-Teleskop für die ursprünglich azimuthale Richtung dar, das in der ursprünglich azimuthalen Richtung einen parallelen Laserstrahl 28 erzeugt. Der rechteckförmige Laserstrahl 22 trifft auf die Zylinderlinse 24, die so im Strahlengang angeordnet ist, dass sich ihr rückwärtiger Linienfokus etwa im Bereich der Rotationsachse 23 befindet. Durch geeignete Wahl der Brennweite der Zylinderlinse 24 wird der Laser-

strahl 27 mit der in der ursprünglich radialen Richtung gewünschten Strahlbreite erzeugt (Fig. 4). Die andere, ursprünglich azimuthale Richtung des Laserstrahls 22 wird durch die Zylinderlinse 24 nicht beeinflusst. Anschließend trifft der Laserstrahl 27 auf den parabolischen Zylinderspiegel 25, der die ursprünglich radiale Richtung des Laserstrahls 22 nicht beeinflusst.

Um Beugungsanteile aus dem rechteckförmigen Laserstrahl 22 auszublenzen, kann entweder eine Blende 29 im Bereich des Linienfokus des Ringsektors 21 des parabolischen Rotationskörpers oder eine Blende 30 im Bereich des Linienfokus des ersten parabolischen Zylinderspiegels 25 angeordnet sein.

Eine Einrichtung 17 zur Formung eines Laserstrahls 8 mit ringsektorförmigem Strahlquerschnitt in einen Laserstrahl 11 mit rechteckförmigem Strahlquerschnitt umfasst einen Spiegel, dessen Oberfläche als Ringsektor 9 eines reflektierenden eines parabolischen Rotationskörpers gestaltet ist. So kann mit nur einem einzigen Spiegel und mit geringen Abbildungsfehlern der ringsektorförmige Laserstrahl 8 in einen rechteckförmigen Laserstrahl 11 geformt werden.

Patentansprüche

1. Einrichtung (17; 20) zur Strahlformung eines Laserstrahls (8) mit ringsektorförmigem Strahlquerschnitt in einen Laserstrahl (11) mit rechteckförmigem Strahlquerschnitt, mit einem Spiegel, dessen Spiegeloberfläche als Ringsektor (9; 21) eines Rotationskörpers gestaltet ist, dadurch gekennzeichnet, dass die Spiegeloberfläche als Ringsektor (9; 21) eines parabolischen Rotationskörpers gestaltet ist.
2. Einrichtung zur Strahlformung nach Anspruch 1, dadurch gekennzeichnet, dass die Spiegeloberfläche durch die konvexe oder die konkave Oberfläche des parabolischen Rotationskörpers gebildet ist.
3. Einrichtung zur Strahlformung nach Anspruch 2, dadurch gekennzeichnet, dass der parabolische Rotationskörper als Rotationsparaboloid ausgebildet ist.

4. Einrichtung zur Strahlformung nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, dass im Linienfokus des Ringsektors (21) des parabolischen Rotationskörpers bzw. im Punktfokus des Ringsektors (9) des Rotationsparaboloids eine Blende (29; 12) vorgesehen ist.
5. Einrichtung zur Strahlformung nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, dass dem Ringsektor (9; 21) ein optisches Element mit einer oder mehreren Oberflächen nachgeordnet ist, die den Laserstrahl jeweils in zwei zueinander rechtwinkligen Richtungen formt bzw. formen.
6. Einrichtung zur Strahlformung nach Anspruch 5, dadurch gekennzeichnet, dass das optische Element als Bifokuslinse ausgebildet ist.
7. Einrichtung zur Strahlformung nach Anspruch 5, dadurch gekennzeichnet, dass das optische Element mehrteilig ausgebildet ist.
8. Einrichtung zur Strahlformung nach Anspruch 7, dadurch gekennzeichnet, dass das optische Element durch eine Zylinderlinse (13; 24) und mindestens einen parabolischen Zylinderspiegel (14; 25, 26) gebildet ist.

9. Laser, umfassend einen coaxialen Laserresonator (1) mit ringförmigem Entladungsraum (2) und ringsektorförmiger Auskoppelöffnung (6) sowie eine Einrichtung (17; 21) zur Strahlformung des aus der Auskoppelöffnung (6) austretenden Laserstrahls (8) nach einem der vorhergehenden Ansprüche.
10. Laser nach Anspruch 9, dadurch gekennzeichnet, dass der Ringsektor (9; 21) des parabolischen Rotationskörpers coaxial zur Ringsektorachse des einfallenden Laserstrahls (8) angeordnet ist.

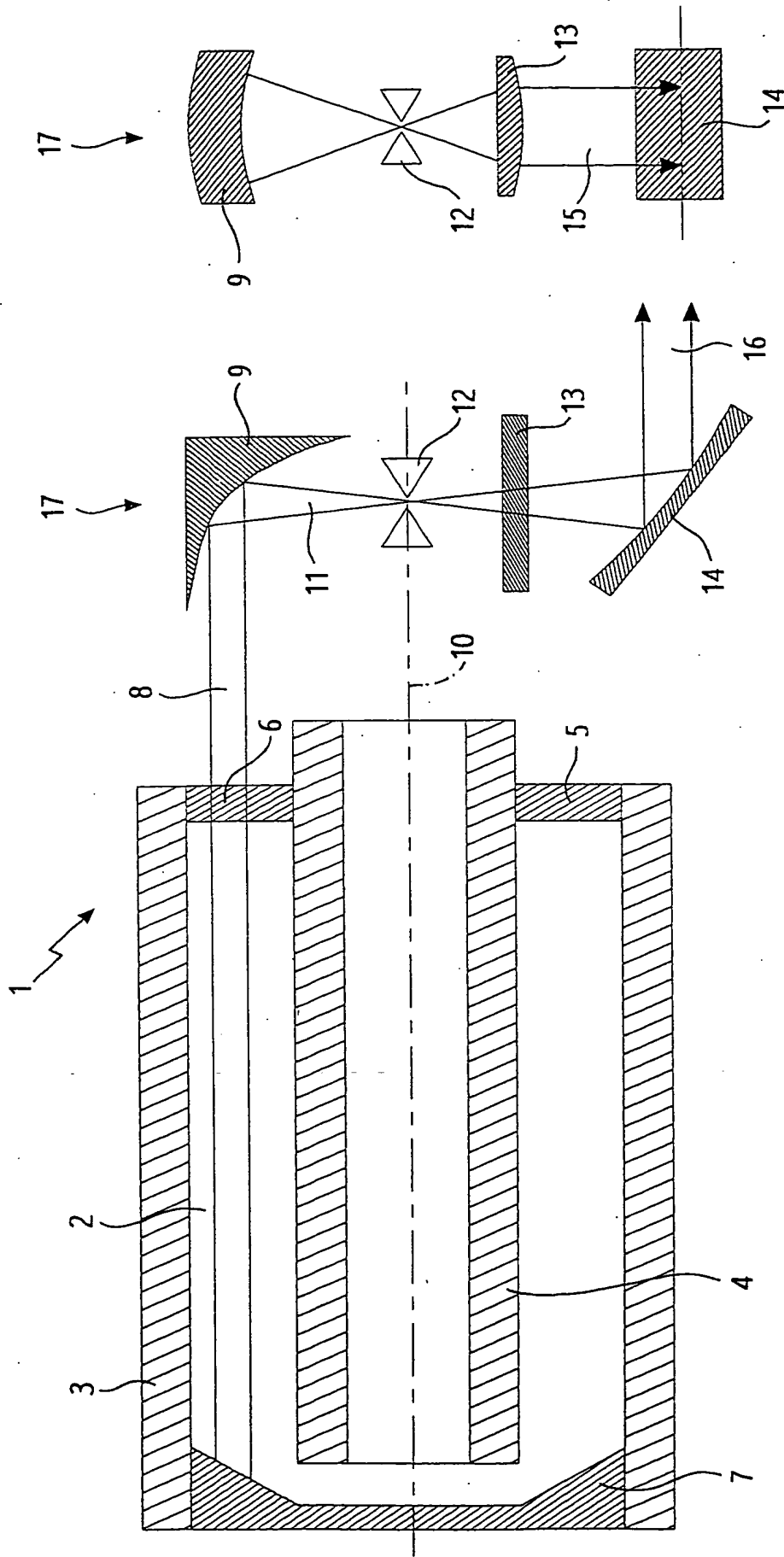


Fig. 1

Fig. 2

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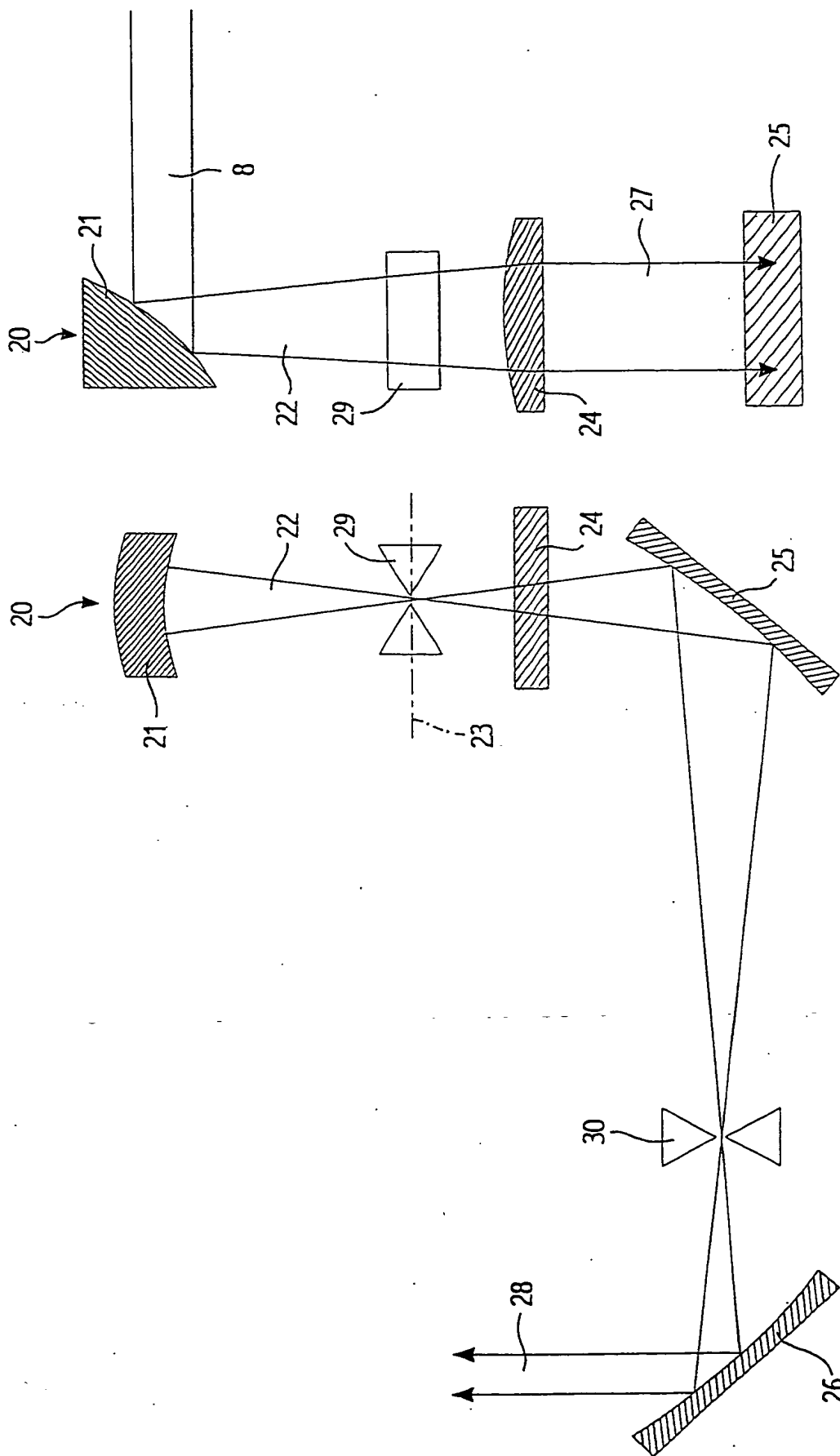


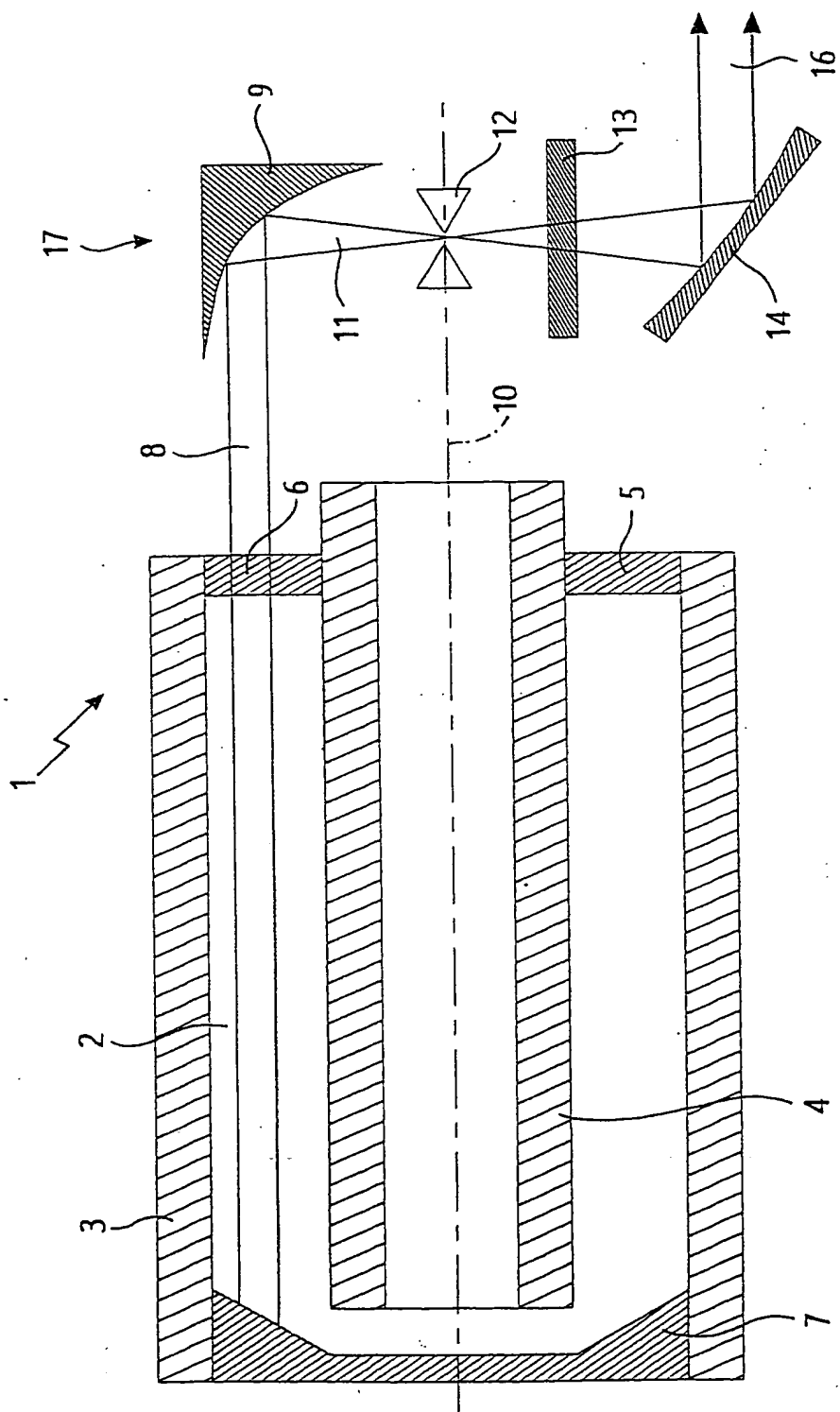
Fig. 4

Fig. 3

Zusammenfassung

Eine Einrichtung (17) zur Formung eines Laserstrahls (8) mit ringsektorförmigem Strahlquerschnitt in einen Laserstrahl (11) mit rechteckförmigem Strahlquerschnitt umfasst einen Spiegel, dessen Oberfläche als Ringsektor (9) eines reflektierenden parabolischen Rotationskörpers gestaltet ist. So kann mit nur einem einzigen Spiegel und mit geringen Abbildungsfehlern der ringsektorförmige Laserstrahl (8) in einen rechteckförmigen Laserstrahl (11) geformt werden.

(Fig. 1)



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Laser-Beam Reformatting System

This invention relates to a system for the reformatting of a laser beam having a circular-sector-shaped beam cross section by means of a mirror whose reflective surface is configured as the circular sector of a rotational body. This type of laser-beam formatting system has been described earlier for instance in DE 44 21 600 C2.

The beam formatting system described in DE 44 21 600 C2 converts a circular-sector-profiled laser beam with radial and/or azimuthal polarization into a rectangular laser beam with linear polarization. To that effect the laser beam is shaped by means of a cone-sector mirror and a parabolic-cylinder mirror, with the line focus of the parabolic-cylinder mirror approximately coinciding with the axis of rotation of the cone-sector mirror. However, this prior-art beam formatting system requires the use of two mirrors. The cone-sector mirror shapes the laser beam in the azimuthal direction but for the focussing or defocussing of the laser beam in the radial direction an additional mirror must be employed. The focal lengths and beam dimensions involved are of an order of magnitude where, in the case of spherical mirrors, spherical aberrations lead to image distortions. To permit a decoupling of the laser beam from the laser resonator it is necessary in the case of the prior-art beam formatting system employing a cone-sector mirror for the cone beam angle to slightly deviate from 90° or for the cone axis to deviate somewhat from a precise coincidence with the line focus of the parabolic-cylinder mirror. As a result, only approximate rectangularity of the beam cross section and linearity of polarization can be obtained.

It is therefore the objective of this invention to introduce a beam-reformatting system of the type referred to above which minimizes image aberrations.

According to the invention, this is accomplished by configuring the reflective surface of the mirror as a circular sector of a parabolic rotational body. The reflective surface may be either the convex or the concave surface of the parabolic rotational body. The parabolic rotational body is preferably in the form of a rotational paraboloid.

A parabolic rotational body is produced by rotating the parabola $z = x^2/a^2 > 0$ around any given axis of rotation that extends parallel to the axis of symmetry of the parabola. The curvature of the parabola is $d^2z/dx^2 = 2/a^2$ and for $a^2 > 0$ it differs in all cases from zero. A circular sector of a parabolic rotational body could also be approximated by an elliptical rotational body. A rotational paraboloid constitutes a special parabolic rotational body in which the axis of rotation coincides with the axis of symmetry of the parabola.

Reflective surfaces in the form of circular sectors of parabolic rotational bodies shape the laser beam both in the azimuthal and in the radial direction. With mirrors of this type no image aberrations whatsoever are encountered, and if there is precise parallelity between the axis of the laser beam and the optical axis, there will be no astigmatic distortions either. The circular sector of a parabolic rotational body produces a line focus on its axis

of rotation, whereas the circular sector of a rotational paraboloid produces a point focus on its axis of rotation.

When the circular sector of the parabolic rotational body is in a coaxial position with the circular-sector axis of the incident laser beam and the circular-sector-shaped laser beam is reflected at the parabolic rotational body by 90° , the radial and/or azimuthal polarization transitions into a linear polarization. The effective focal length of the circular sector of the parabolic rotational body corresponds in the azimuthal direction to the radius of curvature of the circular-sector-shaped laser beam. Reflection by the parabolic rotational body or by the rotational paraboloid reformats the circular-sector-shaped laser beam into a rectangular laser beam while the parabolic rotational-body mirror produces on its axis of rotation a line focus and the rotational-paraboloid mirror produces on its axis of rotation a point focus. Since the optical axis extends parallel to the axis of the laser beam, no astigmatic distortions are engendered and image aberrations as a whole are minimized.

It is desirable to provide in the line focus of the circular sector of the parabolic rotational body or in the point focus of the circular sector of the rotational paraboloid an aperture (spatial filter) which filters undesirable diffraction components (secondary maxima) out of the rectangular laser beam. The relative position between that filter and the line or point focus of the circular sector may be adjustable. A measuring device can be used to detect

the temperature at the filter and to generate a corresponding temperature signal which serves as a control signal for adjusting the adaptive mirror or for moving the aperture.

In preferred design versions of this invention an optical element with one or several surfaces is positioned downstream from the circular sector which surface(s) serve(s) to modify the laser beam in each case so as to extend in two mutually perpendicular directions. This optical element makes it possible at the point of application to form the desired width of the laser beam.

In a variation of this design, the optical element is configured as a single-unit bifocal lens whose rearward focus is preferably positioned in the area of the axis of rotation of the parabolic rotational body.

In another design variation the optical element is configured as a multi-component device, consisting for instance of a cylindrical lens and a parabolic-cylindrical mirror or of a cylindrical lens and two parabolic-cylindrical mirrors. The rearward line focus of the cylindrical lens and/or the rearward line focus of the parabolic-cylindrical mirror is/are preferably positioned in the area of the axis of rotation of the parabolic rotational body. The cylindrical lens may serve both as a vacuum seal on the laser resonator and as an

output window. A parabolic-cylindrical mirror may also be approximated by an elliptic-cylindrical mirror.

The circular sector of the parabolic rotational body and the cylindrical lens can jointly constitute a Galilean telescope for what was the radial and is now the deradiused direction of the circular-sector-shaped laser beam, the circular sector of the parabolic rotational body jointly with a parabolic-cylindrical mirror can constitute a Kepler telescope for what was the azimuthal and is now the deradiused direction, and the two parabolic-cylindrical mirrors can jointly constitute a Kepler telescope in the originally azimuthal direction.

This invention also relates to a laser encompassing a coaxial laser resonator with an annular discharge chamber and a circular-sector-shaped decoupling i.e. output opening as well as a system for beam reformatting as described above. In this case the circular sector of the parabolic rotational body is coaxially aligned with the circular-sector axis of the incident laser beam, i.e. the axis of rotation of the parabolic rotational body coincides with the circular-sector axis of the incident laser beam. This reformats the circular-sector-shaped laser beam with radial and/or azimuthal polarization into a rectangular laser beam with linear polarization.

Other advantageous features of this invention will be evident from the following description and from the diagrams. Also, according to the invention, the features specified above and those explained below may be employed individually or in any desired combination. The design and implementation versions depicted or described are not to be viewed as a limiting enumeration but, instead, merely constitute explanatory examples of this invention.

Fig. 1 illustrates a laser with a coaxial laser resonator and a system per this invention for reformatting the laser beam;

Fig. 2 is a section view, not to scale, of the beam-reformatting system in fig. 1;

Fig. 3 depicts, in a diagram corresponding to that in fig. 1, another system per this invention for reformatting the laser beam; and

Fig. 4 is a section view, not to scale and in a diagram corresponding to that in fig. 2, of the beam-reformatting system illustrated in fig. 3.

Fig. 1 shows a coaxial laser resonator 1 with an annular discharge chamber 2 delimited by a cylindrical outer electrode 3 and, enclosed therein, a cylindrical inner electrode 4. At the right end of the laser resonator 1 in fig. 1, the ring-shaped discharge chamber 2 is delimited by a circular front mirror 5 with a circular-sector-shaped output opening 6 and at the left end by a conical retromirror 7.

The laser beam 8 that exits from the annular discharge chamber 2 through the circular-sector-shaped output opening 6 is radially and/or azimuthally polarized. Moreover, the power density distribution includes undesirable diffraction components (secondary maxima).

On the inside, the circular-sector-shaped laser beam 8 impinges on a 90°-deflecting circular sector 9 of a rotational paraboloid mirror whose axis of rotation 10 extends in a direction that is coaxial with the annular discharge chamber 2 and parallel to the direction of incidence of the laser beam 8 and whose focal length in the azimuthal direction corresponds to the radius of curvature of the circular-sector-shaped cross section of the laser beam 8. The reflection of the circular-sector-shaped laser beam 8 by the circular sector 9 of the rotational paraboloid reformats it into a rectangular (i.e. deradiused) laser beam 11 and a point focus is generated on the axis of rotation 10. Positioned in the area of this point focus is an aperture 12, in particular a nozzle-type filter, which screens

undesirable diffraction components out of the rectangular laser beam 11.

In order for the rectangular laser beam 11 to be of the desired beam width in both directions at the point of its application, a cylindrical lens 13 is interpositioned for beam reformatting in what was originally the azimuthal direction while a parabolic-cylindrical mirror 14, which may also be approximated by an elliptic-cylindrical mirror, is interpositioned for beam reformatting in what was originally the radial direction. The rectangular laser beam 11 impinges on the cylindrical lens 13 which has no effect on the originally radial direction of the rectangular laser beam 11 and which produces a parallel laser beam 15 in the originally azimuthal direction (fig. 2). The parabolic-cylindrical mirror 14 is so placed in the beam path that its rearward line focus is essentially positioned in the area of the axis of rotation 10. Appropriate selection of the focal length for the parabolic-cylindrical mirror 14 produces a radially parallel laser beam 16 of the desired radial beam width.

The circular sector 9, the aperture 12, the cylindrical lens 13 and the parabolic-cylindrical mirror 14 together make up the beam reformatting system 17.

Illustrated in fig. 3 and fig. 4 is a different beam reformatting system 20 in which the circular-sector-shaped laser beam 8 impinges on the outside of the circular sector 21 of a parabolic rotational body. The reflection by the convex outer surface of the circular sector 21 reformats the circular-sector-shaped laser beam into a rectangular laser beam 22 and a line focus is produced on the axis of rotation 23 of the parabolic rotational body.

In order for the rectangular laser beam 22 to be of the desired beam width in both directions at the point of its application, a cylindrical lens 24 is interpositioned for beam reformatting in what was originally the radial direction while two parabolic-cylindrical mirrors 25, 26 are interpositioned for beam reformatting in what was originally the azimuthal direction. The circular sector 21 of the parabolic rotational-body mirror, jointly with the cylindrical lens 24, constitutes a Galilean telescope which generates a parallel laser beam 27 in the originally radial direction, and jointly with the first parabolic-cylindrical mirror 25 it constitutes a Kepler telescope. The two parabolic-cylindrical mirrors 25, 26 jointly constitute another Kepler telescope for the originally azimuthal direction, producing a parallel laser beam 28 in what was originally the azimuthal direction. The rectangular laser beam 22 impinges on the cylindrical lens 24 which is so placed in the beam path that its rearward line focus is essentially positioned in the area of the axis of rotation 23. Suitable selection of the focal length of the cylindrical lens 24 produces a laser beam 27

with a beam width as desired in the originally radial direction (fig. 4). The other, originally azimuthal direction of the laser beam 22 is not affected by the cylindrical lens 24. The laser beam 27 then impinges on the parabolic-cylindrical mirror 25 which in turn does not affect the originally radial direction of the laser beam 22.

For filtering diffraction components out of the laser beam 22, a filter 29 may be positioned in the area of the line focus of the circular sector 21 of the parabolic rotational body, or an aperture 30 may be positioned in the area of the line focus of the first parabolic-cylindrical mirror 25.

A system 17 for the reformatting of a laser beam 8 with a circular-sector-shaped beam cross section into a laser beam 11 with a rectangular beam cross section encompasses a mirror whose surface is shaped as a circular sector 9 of a reflective parabolic rotational body. It is thus possible with only one single mirror to reformat the circular-sector-shaped laser beam 8 into a rectangular laser beam 11 with only minor image aberrations.

Patent Claims

1. System (17; 20) for the beam reformatting of a laser beam (8) having a circular-sector-shaped beam cross section into a laser beam (11) with a rectangular beam cross section, employing a mirror whose reflective surface is shaped in the form of a circular sector (9; 21) of a rotational body, characterized in that the reflective surface is shaped as a circular sector (9; 21) of a parabolic rotational body.
2. Beam reformatting system as in claim 1, characterized in that the reflective surface is constituted of the convex or concave surface of a parabolic rotational body.
3. Beam reformatting system as in claim 2, characterized in that the parabolic rotational body is designed in the form of a rotational paraboloid.

4. Beam reformatting system as in one of the preceding claims, characterized in that a filter (29; 12) is positioned in the line focus of the circular sector (21) of the parabolic rotational body or, respectively, in the point focus of the circular sector (9) of the rotational paraboloid.
5. Beam reformatting system as in one of the preceding claims, characterized in that an optical element is interpositioned after the circular sector (9; 21) which optical element is provided with one or several surfaces serving in each case to reformat the laser beam in two mutually perpendicular directions.
6. Beam reformatting system as in claim 5, characterized in that the optical element is a bifocal lens.
7. Beam reformatting system as in claim 5, characterized in that the optical element consists of several components.
8. Beam reformatting system as in claim 7, characterized in that the optical element is composed of a cylindrical lens (13; 24) and at least one parabolic-cylindrical mirror (14; 25; 26).

9. Laser, encompassing a coaxial laser resonator (1) with an annular discharge chamber (2) and a circular-sector-shaped output opening (6) as well as a system (17; 21) for the beam reformatting of the laser beam (8) exiting from said output opening as per one of the preceding claims.
10. Laser as in claim 9, characterized in that the circular sector (9; 21) of the parabolic rotational body is coaxially aligned with the circular-sector axis of the incident laser beam (8).

Abstract

System (17) for the reformatting of a laser beam (8) having a circular-sector-shaped beam cross section into a laser beam (11) with a rectangular beam cross section, said system incorporating a mirror whose surface is shaped as the circular sector (9) of a reflective parabolic rotational body. With only one single mirror, and entailing only minor image aberrations, the circular-sector-shaped laser beam (8) can be reformatted into a rectangular laser beam (11).

(Fig. 1)

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Laser-Beam-Reformatting-System BACKGROUND OF THE INVENTION

This invention relates to a novel system for the
reformatting reforming of a laser beam having a circular -sector

-shaped beam cross section by means of a mirror ~~whose~~ having a reflective surface ~~is~~ configured as the circular sector of a rotational body.

~~This type of~~ The laser -beam formatting forming system has been described earlier ~~for instance~~ in DE 44 21 600 C2

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~~The beam formatting system described in DE 44 21 600 C2~~ converts a circular -sector -profiled laser beam with radial and/or azimuthal polarization into a rectangular laser beam with linear polarization. To achieve that effect, the laser beam is shaped by means of a cone -sector mirror and a parabolic -cylinder mirror, with and the line focus of the parabolic -cylinder mirror approximately ~~coinciding~~ coincides with the axis of rotation of the cone -sector mirror. However, this prior -art beam formatting forming system requires the use of two mirrors. The cone -sector mirror shapes the laser beam in the azimuthal direction ~~but;~~ however, for the focussing or defocussing of the laser beam in the radial direction, an additional mirror must be employed. The focal lengths and beam dimensions involved are of an order of magnitude ~~where~~ at which, in the case of spherical mirrors, spherical aberrations lead to image distortions.

To permit a decoupling of the laser beam from the laser resonator, it is necessary in the case of the prior art beam ~~formatting~~ forming system employing a cone sector mirror for the cone beam angle to deviate slightly deviate from 90° or for the cone axis to deviate somewhat from a precise coincidence with the line focus of the parabolic cylinder mirror. As a result, only approximate rectangularity of the beam cross section and linearity of polarization can be obtained.

~~It is therefore the~~ Accordingly, it is an objective of ~~this~~ the present invention to ~~introduce~~ provide a novel beam reforming reforming system of the type referred to above which minimizes image aberrations.

~~—3—~~ It is also an object to provide a laser including such a laser beam reforming system in which the laser beam is linearly polarized.

~~According to the invention, this is accomplished by configuring~~

SUMMARY OF THE INVENTION

It has now been found that the foregoing objectives may be accomplished by a beam reforming system in which the reflective surface of the mirror is configured as a circular sector of a parabolic rotational body. ~~The~~ This reflective surface may be either the convex or the concave surface of ~~the~~ a parabolic rotational body. ~~The,~~ and the parabolic rotational body is preferably in the form of a rotational paraboloid.

A parabolic rotational body is produced by rotating the parabola $z = x^2/a^2 > 0$ around any given axis of rotation that extends parallel to the axis of symmetry of the parabola. The curvature of the parabola is $d^2z/dx^2 = 2/a^2$ and for $a^2 > 0$ it differs in all cases from zero. A circular sector of a parabolic rotational body could also be approximated by an elliptical rotational body. A rotational paraboloid constitutes a special parabolic rotational body in which the axis of rotation coincides with the axis of symmetry of the parabola.

Reflective surfaces in the form of circular sectors of parabolic rotational bodies shape the laser beam both in the azimuthal and in the radial direction. With mirrors of this type, no image aberrations whatsoever are encountered, and if there is precise ~~parallelity~~ parallelism between the axis of the laser beam and the optical axis, there will also be no astigmatic distortions ~~either~~. The circular sector of a parabolic rotational body produces a line focus on its axis

—4—

of rotation, whereas the circular sector of a rotational paraboloid produces a point focus on its axis of rotation.

When the circular sector of the parabolic rotational body is in a coaxial position with the circular -sector axis of the incident laser beam and the circular -sector -shaped laser beam is reflected at the parabolic rotational body by 90° , the radial and/or azimuthal polarization transitions into a linear polarization. The effective focal length of the circular sector of the parabolic rotational body corresponds in the azimuthal direction to the radius of curvature of the circular-sector-shaped laser beam. Reflection by the parabolic rotational body or by the rotational paraboloid ~~reformats~~ reforms the circular -sector -shaped laser beam into a rectangular laser beam while the parabolic rotational -body mirror produces on its axis of rotation a line focus and the rotational -paraboloid mirror produces on its axis of rotation a point focus. Since the optical axis extends parallel to the axis of the laser beam, no astigmatic distortions are engendered generated and image aberrations as a whole are minimized.

It is desirable to provide an aperture (spatial filter) in the line focus of the circular sector of the parabolic rotational body or in the point focus of the circular sector of the rotational paraboloid ~~an aperture (spatial filter) which filters to filter~~ undesirable diffraction components (secondary maxima) ~~out of~~ from the rectangular laser beam. The relative position between ~~that~~ the filter and the line or point focus of

the circular sector may be adjustable. A measuring device can be used to detect

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the temperature at the filter and to generate a corresponding temperature signal which serves as a control signal for adjusting the adaptive mirror or for moving the aperture.

In preferred ~~design versions~~ embodiments of this invention, an optical element with one or several surfaces is positioned downstream from the circular sector ~~which~~ and its surface(s) ~~serve(s)~~ serves to modify the laser beam in each case so as to extend in two mutually perpendicular directions. This optical element makes it possible at the point of application to form the desired width of the laser beam.

In a variation of this design, the optical element is configured as a single -unit bifocal lens whose rearward focus is preferably positioned in the area of the axis of rotation of the parabolic rotational body.

In another ~~design variation~~ embodiment, the optical element is configured as a multi-component device, consisting for instance of a cylindrical lens and a parabolic -cylindrical mirror, or of a cylindrical lens and two parabolic -cylindrical mirrors. The rearward line focus of the cylindrical lens and/or

the rearward line focus of the parabolic -cylindrical mirror is/are preferably positioned in the area of the axis of rotation of the parabolic rotational body. The cylindrical lens may serve both as a vacuum seal on the laser resonator and as an

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output window. A parabolic -cylindrical mirror may also be approximated by an elliptic-cylindrical mirror.

The circular sector of the parabolic rotational body and the cylindrical lens can jointly constitute a Galilean telescope for what was the radial and is now the deradiused direction of the circular -sector -shaped laser beam, ~~the~~. The circular sector of the parabolic rotational body jointly with a parabolic -cylindrical mirror can constitute a Kepler telescope for what was the azimuthal and is now the deradiused direction, and the two parabolic -cylindrical mirrors can jointly constitute a Kepler telescope in the ~~originally~~ original azimuthal direction.

This invention also ~~relates~~ applies to a laser encompassing having a coaxial laser resonator with an annular discharge chamber and a circular -sector -shaped decoupling, i.e. output opening as well as a system for beam ~~reformatting~~ reforming as described above. In this case, the circular sector of the parabolic rotational body is coaxially aligned with the circular

-sector axis of the incident laser beam, i.e., the axis of rotation of the parabolic rotational body coincides with the circular -sector axis of the incident laser beam. This ~~reformats~~ reforms the circular -sector -shaped laser beam with radial and/or azimuthal polarization into a rectangular laser beam with linear polarization.

~~7~~ BRIEF DESCRIPTION OF THE DRAWINGS

Other advantageous features of this invention will be evident from the following description and from the ~~diagrams~~. Also, ~~according to the invention,~~ attached drawings, and the features specified above and those explained below hereinafter may be employed individually or in any desired combination. The design and implementation versions depicted or described are not to be viewed as a limiting enumeration but, ~~instead, merely~~ constitute rather explanatory examples of this invention.

Fig. Figure 1 illustrates a laser with a coaxial laser resonator and a system ~~per this~~ embodying the present invention for ~~reformatting~~ reforming the laser beam;

Fig. Figure 2 is a ~~section~~ diagrammatical sectional view, not to scale, of the illustrated beam ~~reformatting~~ reforming system in fig. Figure 1;

Fig. Figure 3 depicts, in a diagram diagrammatical illustration corresponding to that in fig. Figure 1, another system ~~per~~ embodying this

invention for ~~reformatting~~ reforming the laser beam; and

~~Fig.~~ Figure 4 is a ~~section~~ diagrammatical sectional view, not to scale and ~~in a diagram,~~ corresponding to that in ~~fig.~~ the presentation in Figure 2,

of the beam ~~reformatting~~ reforming system illustrated in ~~fig.~~ Figure 3.

—8— DETAILED DESCRIPTION OF THE INVENTION

~~Fig.~~ Figure 1 shows a coaxial laser resonator 1 with an annular discharge chamber 2 ~~delimited by~~ having a cylindrical outer electrode 3 and, enclosed therein, a coaxial cylindrical inner electrode 4. At the right end of the laser resonator 1 in ~~fig.~~ Figure 1, the ring-shaped discharge chamber 2 is ~~delimited~~ closed by a circular front mirror 5 with a circular ~~sector~~ -shaped output opening 6, and at the left end by a conical retromirror 7.

The laser beam 8 that exits from the annular discharge chamber 2 through the circular ~~sector~~ -shaped output opening 6 is radially and/or azimuthally polarized. Moreover, the power density distribution includes undesirable diffraction components (secondary maxima).

On the inside, ~~the~~ of the laser discharge chamber 2, the circular ~~sector~~ -shaped laser beam 8 impinges on a 90° -deflecting circular sector 9 of a rotational paraboloid mirror whose axis of rotation 10 extends in a direction that is coaxial

with the annular discharge chamber 2 and parallel to the direction of incidence of the laser beam 8 ~~and whose~~. Its focal length in the azimuthal direction corresponds to the radius of curvature of the circular -sector -shaped cross section of the laser beam 8. The reflection of the circular -sector -shaped laser beam 8 by the circular sector 9 of the rotational paraboloid ~~reformats~~ reforms it into a rectangular (i.e., deradiused) laser beam 11 and a its focus point ~~focus~~ is generated on the axis of rotation 10. Positioned in the area of this focus point ~~focus~~ is an aperture 12, in particular a nozzle-type filter, which screens

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undesirable diffraction components out of the rectangular laser beam 11.

In order for the rectangular laser beam 11 to be of the desired beam width in both directions at the point of its application, a cylindrical lens 13 is ~~interpositioned~~ interposed for beam ~~reformatting~~ reforming in what was originally the azimuthal direction ~~while,~~ and a parabolic -cylindrical mirror 14, which may also be approximated by an elliptic -cylindrical mirror, is ~~interpositioned~~ interposed for beam ~~reformatting~~ reforming in what was originally the radial direction. The

rectangular laser beam 11 impinges on the cylindrical lens 13 which has no effect on the originally radial direction of the rectangular laser beam 11 ~~and which~~ but it produces a parallel laser beam 15 in the originally azimuthal direction ~~(fig. 2)~~. as seen in Figure 2. The parabolic -cylindrical mirror 14 is so placed in the beam path that its rearward line focus is essentially positioned in the area of the axis of rotation 10. Appropriate selection of the focal length for the parabolic -cylindrical mirror 14 produces a radially parallel laser beam 16 of the desired radial beam width.

The circular sector 9, the aperture 12, the cylindrical lens 13 and the parabolic -cylindrical mirror 14 together make up the beam ~~reformatting~~ reforming system 17.

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Illustrated in ~~fig.~~ Figure 3 and ~~fig.~~ Figure 4 is a different beam ~~reformatting~~ reforming system 20 in which the circular -sector -shaped laser beam 8 impinges on the outside of the circular sector 21 of a parabolic rotational body. The reflection by the convex outer surface of the circular sector 21 ~~reformats~~ reforms the circular -sector -shaped laser beam into a rectangular laser beam 22 and a line focus is produced on the axis of rotation 23 of the parabolic rotational body.

In order for the rectangular laser beam 22 to be of the desired beam width in both directions at the point of its application, a cylindrical lens 24 is ~~interpositioned~~ interposed for beam ~~reformatting~~ reforming in what was originally the radial direction while two parabolic -cylindrical mirrors 25, 26 are ~~interpositioned~~ interposed for beam ~~reformatting~~ reforming in what was originally the azimuthal direction. The circular sector 21 of the parabolic rotational -body mirror, jointly with the cylindrical lens 24, ~~constitutes~~ constitute a Galilean telescope which generates a parallel laser beam 27 in the originally radial direction, and jointly with the first parabolic -cylindrical mirror 25 ~~it-constitutes~~ constitute a Kepler telescope. The two parabolic -cylindrical mirrors 25, 26 jointly constitute another Kepler telescope for the originally azimuthal direction, producing a parallel laser beam 28 in what was originally the azimuthal direction. The rectangular laser beam 22 impinges on the cylindrical lens 24 which is so placed in the beam path that its rearward line focus is essentially positioned in the area of the axis of rotation 23. Suitable selection of the focal length of the cylindrical lens 24 produces a laser beam 27

—11—

with a beam width as desired in the originally radial direction ~~(fig. 4)~~ as shown in Figure 4. The other, originally azimuthal direction of the laser beam 22 is not affected by the cylindrical lens 24. The laser beam 27 then impinges on the parabolic -cylindrical mirror 25 which in turn does not affect the originally radial direction of the laser beam 22.

For filtering diffraction components ~~out of~~ from the laser beam 22, a filter 29 may be positioned in the area of the line focus of the circular sector 21 of the parabolic rotational body, or an aperture 30 may be positioned in the area of the line focus of the first parabolic -cylindrical mirror 25.

A Thus, it can be seen that a system 17 for the ~~reformatting~~ reforming of a laser beam 8 with a circular -sector -shaped beam cross section into a laser beam 11 with a rectangular beam cross section ~~encompasses~~ utilizes a mirror whose surface is shaped as a circular sector 9 of a reflective parabolic rotational body. It is thus possible with only ~~one~~ a single mirror to ~~reformat~~ reform the circular -sector -shaped laser beam 8 into a rectangular laser beam 11 with only minor image aberrations.

24-876-Rk/nu CLAIMS

Patent Claims Having thus described the invention, what is claimed is:

1. ~~System (17; 20) for the beam reformatting~~ 1. A system for the reforming of a laser beam (8) having a circular -sector -shaped beam cross section into a laser beam (11) with a rectangular beam cross section, ~~employing~~ includes in the beam path a mirror ~~whose~~ with a reflective surface ~~is~~ shaped in the form of a circular sector (9; 21) ~~of a rotational body,~~ characterized in that the reflective surface is shaped as a circular sector (9; 21) of a parabolic rotational body.

2. ~~Beam reformatting system as in claim 1, characterized in that the~~ The beam reforming system in accordance with Claim 1, wherein said reflective surface is ~~constituted of~~ the convex or concave surface of a parabolic rotational body.

3. ~~Beam reformatting system as in claim 2, characterized in that the~~ The beam reforming system in accordance with Claim 2, wherein such parabolic rotational body is designed in the form of a rotational paraboloid.

~~4. Beam reformatting system as in one of the preceding claims, characterized in that~~

4. The beam reforming system as in accordance with Claim 2, including a filter (29; 12) is positioned in the line focus of the circular sector (21) of the parabolic rotational body or, respectively, .

5. The beam reforming system as in accordance with Claim 3, including a filter positioned in the point focus of the circular sector (9) of the rotational paraboloid.

~~5. Beam reformatting system as in one of the preceding claims, characterized in that an optical element is interpositioned~~ 6. The beam reforming system in accordance with Claim 1, including an optical element interposed in the beam path after the circular sector (9; 21) which optical element is provided with one or several surfaces serving in each case to reformat, said optical element having at least one surface serving to reform the laser beam in two mutually perpendicular directions.

~~6. Beam reformatting system as in claim 5, characterized in that the 7. The beam reforming system in accordance with Claim 6, wherein said optical element is a bifocal lens.~~

~~7. Beam reformatting system as in claim 5, characterized in that the 8. The beam reforming system in accordance with Claim 6, wherein said optical element consists of several components.~~

~~8. Beam reformatting system as in claim 7, characterized in that the optical element is composed of 9. The beam reforming system in accordance with Claim 8, in which said components of said optical element comprise a cylindrical lens (13; 24) and at least one parabolic -cylindrical mirror(14; 25; 26)..~~

~~—3—~~

~~9. Laser, encompassing a 10. A coaxial laser resonator (1) with an annular discharge chamber (2) and a circular -sector -shaped output opening (6) as well as a system and a beam forming system including a mirror~~

with a reflective surface shaped in the form of a circular sector of a parabolic rotational body.

~~(17; 21) for the beam reformatting of the laser beam (8)~~
exiting from 11. A laser in accordance with Claim 10 wherein
said output
~~opening as per one of the preceding claims.~~

~~10. Laser as in claim 9, characterized in that the circular sector (9; 21) of the~~ said ~~parabolic rotational body is~~
~~coaxially aligned with the circular sector axis of the incident laser beam (8).~~ sector axis of the laser beam incident thereon.

Abstract

~~System (17) for the reformatting~~ A system for the reforming of a laser beam (8) having a circular -sector -shaped beam cross section into a laser beam (11) with a rectangular beam cross section, ~~said system incorporating~~ incorporates a mirror whose surface is shaped as the circular sector (9) of a reflective parabolic rotational body. With only one ~~single~~ mirror, and ~~entailing~~ with only minor image aberrations, the circular -sector -shaped laser beam (8) can be ~~reformatted~~ reformed into a rectangular laser beam(11).

~~(Fig. 1)~~

----- COMPARISON OF HEADERS -----

-HEADER 1-

-HEADER 2-
Header Discontinued

-HEADER 3-
Header Discontinued

----- COMPARISON OF FOOTERS -----

-FOOTER 1-

-FOOTER 2-
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12/12/01-HRT/JRF

-FOOTER 3-
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~~-FOOTER 4-~~
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